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Abundance of soil macroinvertebrates in oak-hickory forests along the Ohio river acidic deposition gradient

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Soil macroinvertebrates were studied from May–September 1989–1990 in ecologically analogous oak-hickory forests across a three-state acidic deposition gradient in Illinois, Indiana, and Ohio. The goal was to quantify the abundance of soil invertebrate communities and to determine if relationships exist between the numbers of soil macroinvertebrates and soil chemical properties along the deposition gradient. The animals were sampled to a soil depth of 20 cm using 10.5 cm diameter cores. There were significant differences in the numbers of total macroinvertebrates averaged across all dates among the three study sites across the deposition gradient. The overall effect of this deposition on total numbers of soil macroinvertebrates was negative. Their abundances were in the order (highest to lowest): Illinois > Indiana > Ohio. Significant correlations of the abundance of total soil macroinvertebrates with soil pH, concentration of extractable sulfate in the A_1 horizon, and coefficients of total sulfur and nitrogen loadings suggest that these organisms could have been affected by acidic deposition in the region.

1. Introduction

Several studies have shown that experimental acidification and liming of soil may affect populations of soil animals. The most detailed of them were conducted in Scandinavian coniferous forests (Abrahamsen 1983, Bääth et al. 1980, Hågvar 1987, Hågvar 1988, Hågvar & Abrahamsen 1984, Huhta 1984, Huhta et al. 1983, Koskenniemi & Huhta 1986, Vilkamaa & Huhta 1986). However, most of these studies were conducted on experimental plots or in laboratory microcosms over short periods of time. Studies of the long-term (more than ten years) effects of acidic deposition are few. They include primarily surveys along a point source pollution gradient (Kilham & Wainwright 1981). The goal of this project was to quantify the composition and abundance of the soil macroinvertebrate community (mesofauna) at several study sites along the regional gradient in sulfate (SO_4^{2-}) deposition in the lower midwestern part of the USA along the Ohio River Valley (the Ohio Corridor Study), the area which had high levels of wet and dry acidic deposition throughout most of this century (Loucks 1992). Specifically, relationships between the abundance of soil invertebrates and changes in soil properties along the gradient were investigated.

2. Materials and methods

This study was conducted along the Ohio Corridor gradient from high long-term levels of sulfate and nitrate deposition in the Edge-of-Appalachia preserve in southern Ohio, to intermediate levels in Hoosier National Forest in Indiana and finally to low levels in Touch-of-Nature Preserve in southern Illinois. The study sites follow generally parallel climate isopleths resulting in relatively uniform climate along the gradient (Foster 1990). The acidic deposition amounts, temperature and precipitation at each study site have been reported by other cooperators in the Ohio Valley Gradient study, as have the differences in soil chemistry and the correlations between these two (Loucks, 1990). Analysis of historical data on concentration and wet deposition patterns over 30 years prior to 1985 was summarized by Armentano & Loucks (1990).

Macroinvertebrates were sampled in May and August in 1989 and 1990. The abundance of soil macroinvertebrates was estimated from soil cores (10.5 cm diameter and 20 cm deep). Animals were extracted from samples by handsorting with an illuminated desk magnifier. Six soil cores were taken in the four sampling plots ($n = 24$ site/date). The abundance of earthworms was determined by excavating 0.25 m^2 quadrats ($n = 20$ site/date) to a depth of 30 cm at 10 cm increments and hand sorting them on the site. Abundance of soil macroinvertebrates was expressed as the number per square meter to a depth of 20 cm. Sampling at all study sites was completed within ten days from the beginning of each sampling period to minimize phenological changes in soil invertebrate communities in study sites across 500 km gradient.

All macroinvertebrate data were transformed prior to statistical analysis to normalize distribution using formula log (x+1). Two-way analysis of variance was used to test for overall significant differences in numbers of total macroinvertebrates among study sites and among sampling periods. Bonferroni t tests were performed to determine where significant differences occurred. Correlation analyses (Pearson correlation coefficient) were done to test for significant relationships between soil pH, % AFDM (ash-free dry mass), CEC, SO_4^{2-}, % S, % N, TSLR (total sulfur loading ratio), TNLR (total nitrogen loading ratio) and abundance of total macroinvertebrates across all sites. Statistical analyses was done using SAS (SAS Institute 1985).

3. Results

There were significant differences in the numbers of total macroinvertebrates (Table 1) extracted from the top 20 cm averaged across all dates among the three study sites across the deposition gradient. A two-way ANOVA indicated a significant effect of study site and date of sampling on numbers of total macroinvertebrates (Table 2). Abundances of total soil macroinvertebrates per square meter in the study sites in oak-hickory forests across the deposition gradient were in the order (highest to lowest): Illinois > Indiana > Ohio. Illinois, the low-dose site, was significantly different from the other two sites as determined by Bonferroni t test following the overall ANOVA. Indiana and Ohio sites were not significantly different from each other. There was no significant site × date interaction effect, indicating that differences among study sites were generally consistent across all sampling dates during two years. There was, however, significant site × year interaction effect, since differences between sites occurred mostly in 1989 (Table 1). This year was preceded by severe drought in the region. Numbers of total soil macroinvertebrates were similar at all sites in 1990 following two years of normal precipitation, however. Abundance of earthworms in separate, 0.25 m^2 samples, declined from 20–30 ind./m^2 in Illinois to 1–2 individuals/m^2 in Indiana and Ohio (Table 1).

Table 1. Numbers of total soil invertebrates and earthworms in survey data. Means with the same letter are not significantly different at the 0.05 level. Sample size 96 and 80, respectively.

	Illinois	Indiana	Ohio
All macroinv.			
1989	1908^{a}	847^{b}	651^{b}
1990	1725^{a}	1636^{a}	1600^{a}
Overall mean	1853^{a}	1242^{b}	1126^{b}
Earthworms			
1989	33.0^{a}	0	1.0^{b}
1990	25.0^{a}	0.8^{b}	1.0^{b}
Overall mean	29.0^{a}	0.4^{b}	1.0^{b}

Changes in soil chemistry in oak-hickory forests along acidic deposition gradient were reported in detail by Loucks & Somers (1990) and are presented here only to illustrate differences in the chemical environment of habitats of soil invertebrates as affected by the long-term acidic deposition. There were significant differences in the soil pH, percent C, and extractable sulfate (SO_4^{2-}) in the samples of A_1 horizons across the three study sites. Mean soil pH in the A_1 horizon decreased from 4.57 in the Illinois site to pH 3.9 in the Indiana and Ohio sites. Amount of carbon in the A_1 horizon increased from 2.08 in the low-dose site in Illinois to 7.84 in Ohio. Water extractable sulfate increased from 33.4 mg/L in Illinois to 74.2 mg/L in Ohio. There was an increase in H^+ and Al^{3+} on the exchange sites at the Ohio study site resulting in higher CEC in comparison with the Illinois reference site. When differences in the soil pH were evaluated in relation to the total sulfate inputs and the exchangeable neutralizing cations (sum of exchangeable Ca, Mg, Na, and K), the Illinois site was found to be less sensitive than the Indiana and Ohio sites. The total sulfur loading ratio accounted for much of the variation in pH of the A_1 horizon along the long-term deposition gradient (Loucks & Somers 1990).

Correlation analysis was done to determine if a relationship exist between the abundance of total macroinvertebrates and selected soil chemical variables that are usually affected by acidic deposition and have a potential to directly or indirectly affect the soil invertebrate community in study sites along the acidic deposition gradient. This analysis tested for significant relationships between soil pH, AFDM, % C, % S, % N, CEC, SO_4^{2-}, TSLR and TNLR, and total abundance of soil macroinvertebrates (Table 3). Correlation analysis indicated that

Table 2. Summary table of analysis of variance of total soil macroinvertebrates survey data.

Source of variation	*df*	*F*	*P*
Site	2	18.65	0.0001
Date	3	24.99	0.0001
Year	1	71.88	0.0001
Site × Date	2	1.81	0.1649
Site × Year	2	22.98	0.0001
Error	368		
Total	383		

total macroinvertebrate numbers across the three sites were significantly positively related to soil pH ($P = 0.03$) and significantly negatively related to the amount of soil extractable sulfate ($P = 0.022$), percent carbon ($P = 0.018$), cation exchange capacity ($P = 0.028$), total nitrogen content ($P = 0.47$) and both TSLR and TNLR ($P = 0.034$ and $P = 0.032$ respectively). There was no significant correlation between the abundance of soil macroinvertebrates and % AFDM ($P = 0.131$) and total sulfur content of soils ($P = 0.08$). These results suggest that total macroinvertebrate abundances in oak-hickory forests in the Ohio River Valley may be explained on the basis of soil pH, % C, CEC, SO_4^{2-}, TSLR and TNLR. However, these variables are sensitive to acidic deposition in the soils with very low cation content implying that long-term acidic deposition in the region could have been the driving factor affecting directly or indirectly the soil macroinvertebrate community in the region.

4. Discussion

Changes in soils of oak-hickory forests along the gradient are consistent with expected effects of acidic deposition. The sites which received greatest cumulative dose and had the longest period of high deposition (Ohio and Indiana) had lower pH and greater organic matter content than the site in Illinois which received a lower dose of acidic deposition. The lower levels of base cations along the gradient from the low-dose Illinois site to the high-dose sites in Indiana and Ohio is proportional to the estimates of 86-yr cumulative deposition of SO_4^{2-} and NO_3^- (Loucks 1992).

Significant correlations of the abundance of total soil macroinvertebrates with soil pH, concentration of extractable sulfate in the A_1 horizon, and coefficients of total sulfur and nitrogen loadings suggest that these organisms could have been affected by acidic deposition in the region. The overall effect of this deposition on total numbers of soil macroinvertebrates was negative. This is in agreement with findings in several studies. The detrimental effect of soil acidification was reported for different groups of soil invertebrates including earthworms (Reynolds 1971, Hågvar 1980, Ma et al. 1990, Esher et al. 1992) and enchytraed worms (Bääth et al. 1980, Hågvar & Abrahamsen 1977, Lundkvist 1977). Application of high levels (ten-times annual sulfate deposition) of nonacidic SO_4^{2-} salt treatments was reported to reduce abundance of litter macroarthropods (Craft & Webb 1984). However, the reaction of soil invertebrates to acidic deposition is not uniform. Certain species are characterized as "acidophilic" and were reported to increase their abundance in acidified soils (Bääth et al. 1980, Hågvar & Abrahamsen, 1977, Hågvar, 1978, 1980, 1984, 1987). Further taxonomic identification of macroinvertebrates extracted from soil samples will allow one to determine changes in the population sizes of species differently susceptible to acidic-deposition-induced alterations of the soil environment.

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Table 3. Correlation matrix for soil characteristics and abundance of soil macroinvertebrates in oak-hickory forests across regional acidic deposition gradient. Only significant correlations ($P < 0.05$, two-tailed test) are entered, ns = not significant

	Abundance	pH	%AFDM	%C	CEC	SO_4^{-2}	%S	%N	TSLR
pH	0.36								
%AFDM	ns	–0.77							
%C	–0.39	–0.62	0.367						
CEC	–0.37	–0.78	0.80	0.89					
SO_4^{-2}	–0.38	–0.68	0.48	0.74	0.75				
%S	ns	–0.66	ns	0.63	0.35	0.46			
%N	–0.33	–0.72	ns	0.85	0.74	0.72	0.51		
TSLR	–0.35	ns	ns	0.49	0.74	0.83	ns	0.67	
TNLR	–0.36	ns	ns	0.49	0.59	0.83	ns	0.68	1.00

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